FIRST MEASUREMENT OF INTERFERENCE FRAGMENTATION ON A TRANSVERSELY POLARIZED HYDROGEN TARGET

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The HERMES experiment has measured for the first time single target-spin asymmetries in semi-inclusive two-pion production using a transversely polarized hydrogen target. These asymmetries are related to the product of two unknowns, the transversity distribution function and the interference fragmentation function. In the invariant mass range 0.51 GeV $< M_{\pi^+\pi^-} <$ 0.97 GeV the measured asymmetry deviates significantly from zero, indicating that two-pion semi-inclusive deep-inelastic scattering can be used to probe transversity.

1. Introduction

An important missing piece in our understanding of the spin structure of the nucleon is the transversity distribution $h_1(x)$. It is the only one of the three leading-twist quark distribution functions, $f_1(x)$, $g_1(x)$ and $h_1(x)$, that so-far remains unmeasured. The function $h_1(x)$ describes the distribution of transversely polarized quarks in a transversely polarized nucleon. It is quite difficult to measure $h_1(x)$, since it is a chiral-odd function, which can only be probed in combination with another chiral-odd function. This can be done in semi-inclusive DIS, where the second chiral-odd object is a fragmentation function, describing the fragmentation of the struck quark into one or more final-state hadrons.

HERMES is one of the pioneering experiments on this subject. The structure function $h_1(x)$ is probed by measuring various single-spin asymmetries. First, a longitudinally polarized target [1] was used and more recently a transversely polarized target was used [2]. In these experiments, single spin asymmetries (SSA's) were only measured for *single-hadron* semi-inclusive DIS (SIDIS). However, already in 1993 Collins et al. [3] and in 1998

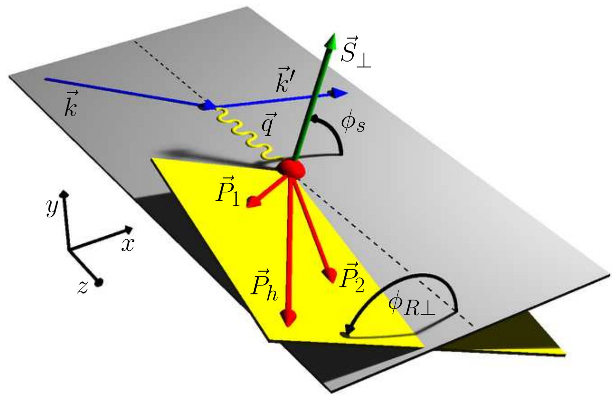

Figure 1. Kinematic planes, where $\phi_{R\perp}$ is the angle between the plane spanned by the incident ($\vec{k}$) and scattered lepton ($\vec{k}'$) and the plane spanned by the two detected pions $\vec{P}_1$ (π^+) and $\vec{P}_2$ (π^-) with $\vec{P}_h \equiv \vec{P}_1 + \vec{P}_2$.

Jaffe et al. [4] suggested to study transversity in two-hadron SIDIS. Although this comes at the expense of a larger statistical uncertainty, there is a good reason for looking at SSA's in two-hadron SIDIS: the measured SSA's relate directly to the product of $h_1(x)$ and the fragmentation function, whereas in single-hadron SIDIS this product is convoluted with the transverse momentum of the hadron. Also measuring SSA's in two-hadron SIDIS provides an independent method of measuring $h_1(x)$, since it involves a different fragmentation function as compared to single-hadron SIDIS.

In order to finally extract the structure function $h_1(x)$, one needs to know the value of the involved fragmentation function. Although this function is also still unknown, it can be cleanly measured in e^+e^- experiments, such as Belle and Babar.

2. Single Spin Asymmetry

The transversity distribution can be accessed experimentally by measuring the single target-spin asymmetry, defined as:

$$\begin{aligned} A_{UT}(\phi_{R\perp}, \phi_S, \theta) &= \frac{1}{|S_T|} \frac{N^\uparrow(\phi_{R\perp}, \phi_S, \theta)/N^\uparrow_{\mathrm{DIS}} - N^\downarrow(\phi_{R\perp}, \phi_S, \theta)/N^\downarrow_{\mathrm{DIS}}}{N^\uparrow(\phi_{R\perp}, \phi_S, \theta)/N^\uparrow_{\mathrm{DIS}} + N^\downarrow(\phi_{R\perp}, \phi_S, \theta)/N^\downarrow_{\mathrm{DIS}}} \\ &= \frac{\sigma_{UT}}{\sigma_{UU}}, \end{aligned} \quad (1)$$

where UT refers to Unpolarized beam and Transversely polarized target. The asymmetry is evaluated as a function of the angles $\phi_{R\perp}$, ϕ_S and θ

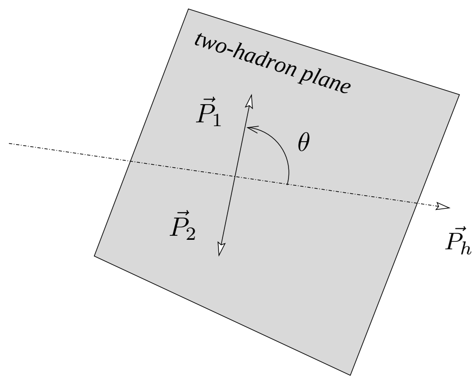

Figure 2. Description of the polar angle θ, in the center-of-mass frame of the two pions. The vector $\vec{P}_h$ is evaluated in the hadronic center-of-mass system.

which are defined in Fig. 1 [a] and 2. Explicitly:

$$\phi_{R\perp} = \frac{\vec{q}\times\vec{k}\cdot\vec{R_T}}{|\vec{q}\times\vec{k}\cdot\vec{R_T}|}\cos^{-1}\frac{\vec{q}\times\vec{k}\cdot\vec{q}\times\vec{R_T}}{|\vec{q}\times\vec{k}||\vec{q}\times\vec{R_T}|} \tag{2}$$

and

$$\phi_S = \frac{\vec{q}\times\vec{k}\cdot\vec{S}_\perp}{|\vec{q}\times\vec{k}\cdot\vec{S}_\perp|}\cos^{-1}\frac{\vec{q}\times\vec{k}\cdot\vec{q}\times\vec{S}_\perp}{|\vec{q}\times\vec{k}||\vec{q}\times\vec{S}_\perp|}. \tag{3}$$

where R_T is the component of R ($\vec{R}\equiv(\vec{P_1}-\vec{P_2})/2$) perpendicular to P_h ($\vec{P_h}\equiv\vec{P_1}+\vec{P_2}$), i.e. $\vec{R_T}=R-(R\cdot\hat{P_h})\hat{P_h}$.

The azimuthal angle ϕ_S represents the spin direction of the target "$\uparrow$" state and $N^{\uparrow(\downarrow)}(\phi_{R\perp},\phi_S,\theta)$ is the number of semi-inclusive $\pi^+\pi^-$-pairs in the target $\uparrow(\downarrow)$ spin state. These numbers are normalized to the corresponding number of DIS events, $N^{\uparrow}_{\mathrm{DIS}}$ and $N^{\downarrow}_{DIS}$, respectively. The quantity $|S_T|$ indicates the average target polarization. The asymmetry is equal to the ratio of σ_{UT} and σ_{UU}, which are the polarized and unpolarized cross sections, respectively. According to Bacchetta et al. [6] σ_{UT} can be written at leading-twist[b] as:

$$\begin{aligned}\sigma_{UT} = -\sum_q \frac{\alpha^2 e_q^2}{2\pi Q^2 y}(1-y)|\vec{S}_\perp|\frac{|\vec{R}|}{M_{\pi\pi}}\sin(\phi_{R\perp}+\phi_S)\sin\theta h_{1,q}(x)\\ \times\left[H_{1,q}^{\sphericalangle,sp}(z,M_{\pi\pi}^2)+\cos\theta H_{1,q}^{\sphericalangle,pp}(z,M_{\pi\pi}^2)\right]\end{aligned} \tag{4}$$

[a]The angle definitions are consistent with the "Trento Conventions" [5].
[b]See [6] for the sub-leading twist expression.

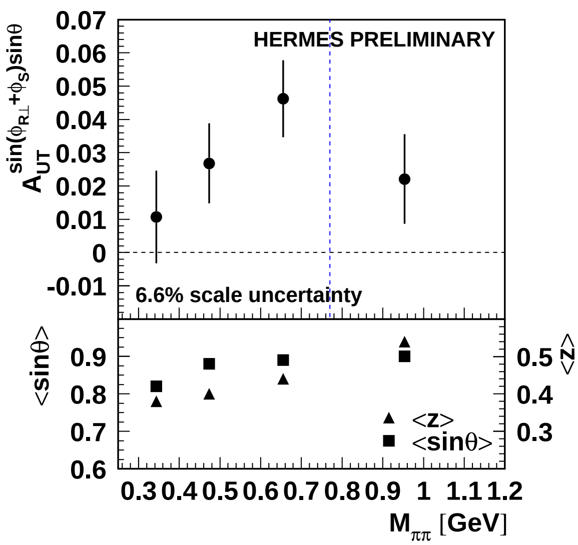

Figure 3. The asymmetry $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ versus the invariant mass of the $\pi^+\pi^-$-pair (using mass binning, with the bin boundaries at 0.25, 0.40, 0.55, 0.77, 2.0 GeV).

where $|\vec{R}| = \frac{1}{2}\sqrt{M_{\pi\pi}^2 - 4M_\pi^2}$ with $M_{\pi\pi}$ the invariant mass of the pion pair, M_π the pion mass and x, y and z the standard scaling variables used in semi-inclusive DIS. The transversity distribution $h_1(x)$ couples to a combination of two-hadron interference fragmentation functions, $H_1^{\sphericalangle,sp}$ and $H_1^{\sphericalangle,pp}$. These functions describe the interference between different production channels of the pion pair; $H_1^{\sphericalangle,sp}$ relates to the interference between s- and p-wave states and $H_1^{\sphericalangle,pp}$ to the interference between two p-wave states.

A two-dimensional fit function of the form

$$f(\phi_{R\perp} + \phi_S, \theta) = p_0 + p_1 \sin(\phi_{R\perp} + \phi_S)\sin\theta \qquad (5)$$

was used to extract from the measured asymmetry the part related to the product $h_1 H_1^{\sphericalangle,sp}$, where $p_1 \equiv A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$.

3. Results

The present results are based on data taken in the period from 2002 until 2004 using a transversely polarized hydrogen target in the HERMES experiment at DESY. The average target polarization, $|S_T|$, was 75.4 ± 5.0 %.

In Fig. 3 the data for $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ are shown versus the invariant mass of the $\pi^+\pi^-$-pair. The asymmetry is clearly positive over the entire

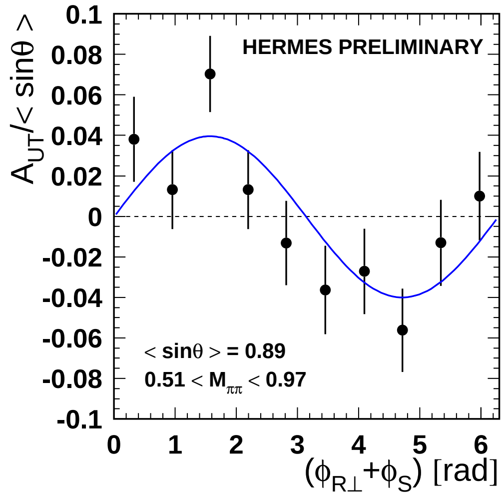

Figure 4. The asymmetry A_{UT} divided by the average $\langle \sin\theta \rangle$ versus the angle combination $(\phi_{R\perp} + \phi_S)$.

invariant mass range and largest in the region of the ρ^0 mass. The corresponding invariant mass distribution is shown in the left plot of Fig. 5. Whereas the results on SSA's in two-hadron fragmentation using a *longitudinally* polarized deuterium target [8] gave a hint of a sign change of the asymmetry at the ρ^0 mass (0.770 GeV) as predicted in [4], the new results presented here are clearly inconsistent with such behavior. However, a good description of the data is given by a refined version [9] of a prediction which uses a spectator model for the fragmentation functions [10].

In Fig. 4 the raw asymmetry is shown in bins of $\phi_{R\perp} + \phi_S$, integrated over the invariant mass range 0.51 GeV $< M_{\pi\pi} <$ 0.97 GeV. This plot shows that a clear $\sin(\phi_{R\perp} + \phi_S)$ behavior is present in the data. The plot includes a curve resulting from fitting the data with $f(\phi_{R\perp} + \phi_S) = p_0 + p_1 \sin(\phi_{R\perp} + \phi_S)$, where $p_1 \equiv A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta} = 0.040 \pm 0.009$ (stat) $\pm$ 0.003 (syst). Due to the peaked shape of the θ-distribution (right plot in Fig. 5) the asymmetry is mostly evaluated around $\theta = \frac{\pi}{2}$. Therefore the value of $A_{UT}^{\sin(\phi_{R\perp}+\phi_S)\sin\theta}$ is insensitive to whether one uses this one-dimensional fit function, integrating over θ, or a two-dimensional one, like eq. 5.

Data taking with a transversely polarized hydrogen target will continue until November 2005 after which the analysis of the full data sample is

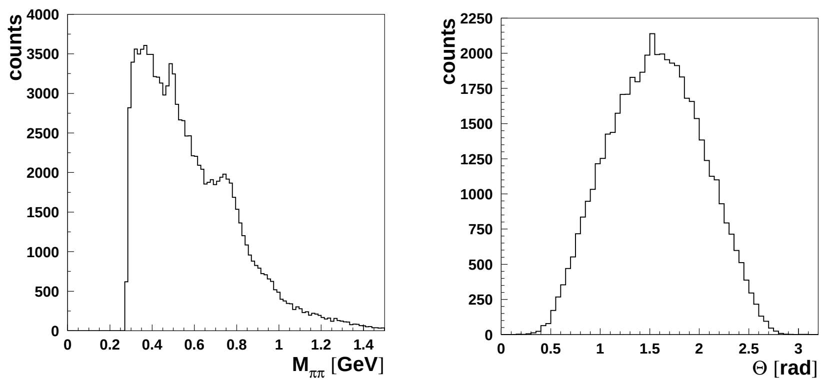

Figure 5. The left plot shows the distribution of the invariant mass of the $\pi^+\pi^-$-pairs and the right plot shows the distribution of the angle θ (for the invariant mass range 0.51 GeV $< M_{\pi\pi} <$ 0.97 GeV.

expected to lead to a decrease of the uncertainty on the asymmetry with approximately a factor of $\sqrt{2}$. Further steps in the analysis include looking at the part of the asymmetry coupling to $H_1^{\sphericalangle,pp}$ and studying the x and z dependence of the asymmetries.

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